Improving our Understanding of Tropical Cyclone Genesis

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LONG-TERM GOALS

To improve understanding of tropical cyclone genesis through a research program combining high-resolution modeling and detailed observational studies to investigate detailed physical processes by which a tropical cyclone forms.

OBJECTIVES

The objective is to investigate the detailed physical processes that occur in a cloud cluster as it interacts with the immediate environment such that a tropical cyclone forms. Specific investigations include:

1. detailed investigation of the mesoscale processes associated with genesis.
2. detailed investigation of the microphysical properties that distinguish developing cloud clusters from non-developing cloud clusters.
3. simulations of real cases that develop within known favorable large-scale patterns in the western North Pacific.

Through diagnostic analysis of these experiments, insights will be gained that will contribute to improvement of the forecasts associated with tropical cyclone genesis, particularly in the western North Pacific Basin.

APPROACH

The primary question to be addressed is to understand the mesoscale and microphysical differences between cloud clusters that do develop into tropical cyclones (TC) and those that do not. Because the problem is not just an issue of the differences of structure within the cloud cluster itself, but is also an issue of how the cloud cluster interacts with the surrounding large-scale environment, a two-tiered approach is planned. In the first part of the research, the work of Ritchie 1995, Ritchie and Holland 1997, and Simpson et al. 1997 is extended via a series of simulations that incorporate the general structure of the western North Pacific environment but changes the mesoscale details of the cloud cluster under investigation. Through a series of high-resolution sensitivity simulations we can determine whether it is the *mesoscale* structure of the cloud cluster itself that determines whether it will develop into a tropical cyclone or not. Simulations will be run that focus on the mesoscale structure of developing and non-developing cloud clusters in an idealized framework at 1-km

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14. ABSTRACT
To improve understanding of tropical cyclone genesis through a research program combining high-resolution modeling and detailed observational studies to investigate detailed physical processes by which a tropical cyclone forms.

15. SUBJECT TERMS

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resolution to incorporate more realistic cloud microphysical processes, which are likely to be important in genesis processes where deep thunderstorms (Riehl and Malkus 1961) provide the initial energy required to initiate a tropical cyclone (Ritchie et al. 2003). Analysis of these idealized sensitivity simulations will help understand the mesoscale atmospheric conditions necessary for a cloud cluster to develop into a tropical cyclone.

In addition to the idealized simulations, several real-case simulations of western North Pacific genesis will be run. Several recent cases of developing and non-developing cloud clusters within the large-scale patterns for genesis identified in Ritchie and Holland (1999) in the western North Pacific will be identified using lightning data (if available) or microwave imagery (Leary and Ritchie 2009). We would like to be able to run these simulations with initial conditions that accurately specify the 3-dimensional dynamic and thermodynamic structure of both cloud clusters that develop and those that do not. The real-case simulations of cloud clusters should illuminate the important interactions between the mesoscale structure of the cloud cluster and the surrounding environment that either result in tropical cyclogenesis or causes the cloud cluster to dissipate without development.

WORK COMPLETED

Remotely-sensed data have been investigated for their ability to discriminate between developing and non-developing cloud clusters. In a companion study, lightning data from the Long-range Lightning Detection Network (LLDN) have been used in the eastern Pacific during the 2006 season to investigate differences in convective activity (and thus also microphysical differences) in cloud clusters (Leary and Ritchie 2008). In addition, signals have been developed using infra-red brightness temperatures from the GOES satellites to detect: 1) intensity of a tropical cyclone; and 2) genesis of a tropical cyclone (Piñeros et al. 2008, 2009; Piñeros 2008a,b, 2009). This work is being extended to include other years. Currently the period 2004 -2005 has been completed.

The WRF model has been used to simulate:

1. real cases of tropical cyclogenesis in the western, eastern North Pacific and Atlantic matching cases investigated using the above remotely-sensed data;
2. real cases of non-developing cloud clusters embedded in apparently favorable conditions; and
3. idealized cases of tropical cyclone genesis.

RESULTS

Recent results from a study that extracts information from infrared imagery to discriminate developing from non-developing cloud clusters has demonstrated skill in detecting genesis. The deviation-angle variance technique (Piñeros et al. 2009) is based on calculating an arbitrary cloud cluster's departure from axisymmetry: the more axisymmetric the cloud is, the more similar to a perfect, symmetric TC. When the calculated value dips below a threshold value of variance the cloud cluster will continue to develop into a tropical storm. The technique can detect genesis up to 100 hours in advance with a mean detection time of 27 hours in advance for the combined 2004 and 2005 Atlantic seasons (Pineros et al. 2009; Ritchie et al. 2009). With a threshold variance of 1700, the technique detected 86% of the developing cloud clusters, with a false alarm rate of 22%. As shown in the ROC curve (Fig. 2a) this ratio can be varied to satisfy forecaster requirements.

The variance value also has demonstrated that it correlates well with the actual intensity of tropical cyclones. A one-to-one correspondence of variance with intensity for the intensifying periods for

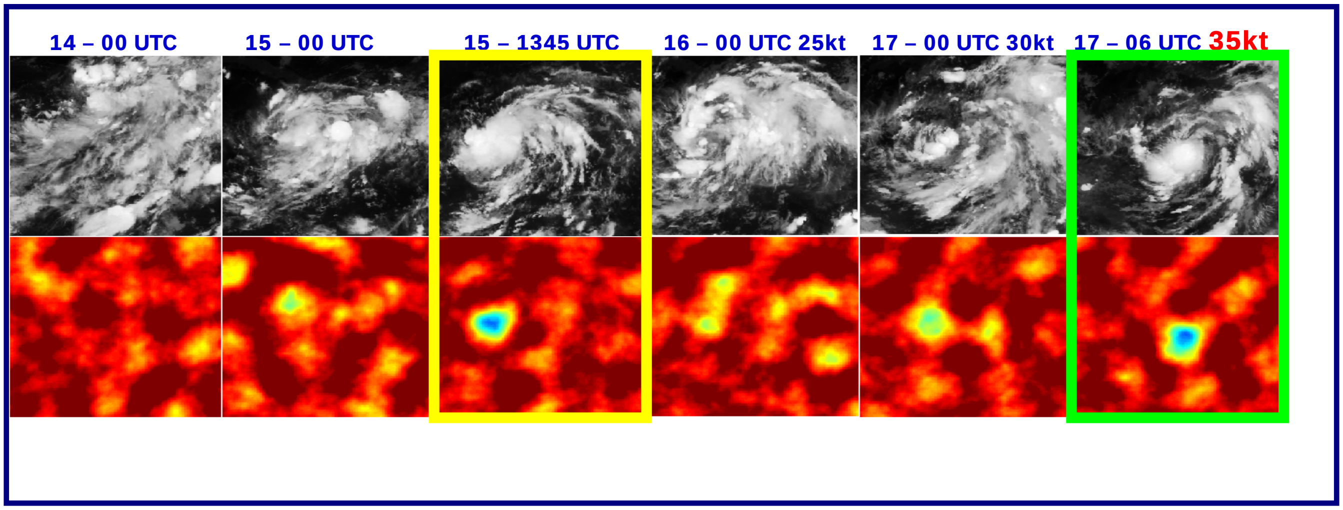

Figure 1: Infrared image series for Hurricane Wilma (2005) and the corresponding spatial variance pattern for each image. In this instance, a threshold value of variance of 1700 detected the developing cloud cluster 7 hours in advance of the first advisory by NHC.

tropical cyclones from 2005 was developed (Fig. 2b) and then tested on the 2004 season for approximately 3800 images. A root mean square (RMS) wind speed error of approximately 19.4 kt was obtained over all intensity bins. Ninety percent of the samples had an RMS error of ~ 14.1 kt and 50% of the samples had an RMS error ~ 5.2 kt demonstrating that much of the RMS error was due to a few outliers. The Dvorak technique has a reported RMS error of about 10-15 kt (Brow and Franklin 2002). However, inspection of the NHC intensity curves in the annual reports (Beven et al. 2008) shows that there is considerable variability in the Dvorak estimates obtained from different agencies. Thus, not only does this deviation-angle-variance intensity estimate compare favorably with Dvorak estimates, but the subjectivity that results in different Dvorak estimates depending on the analyst is not present in this technique – it is completely objective.

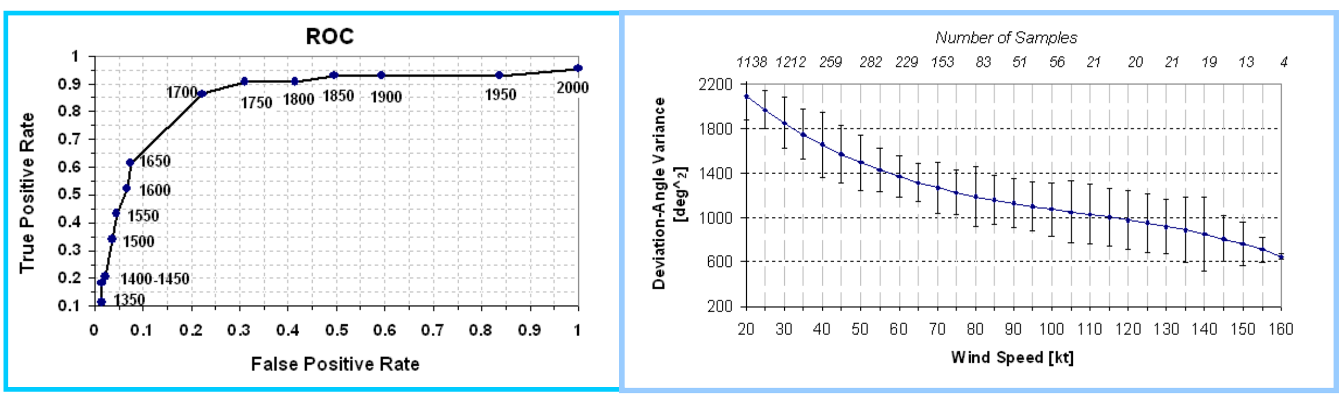

Figure 2: a) Preliminary receiver operating characteristic curve for detection of developing cloud clusters using the infrared technique described in Piñeros et al. (2008; 2009) for 2004 and 2005 Atlantic storms; and b) the one-to-one correspondence of the variance value to intensity for 2005 TCs for intensifying periods.

Two simulations of cloud clusters that developed in the western North Pacific were investigated in detail for the relative roles of environmental versus convective-scale contributions to their development (Fig. 3) (Penny and Ritchie 2008; 2009a; b). Although the storms were unalike in both size and structure and developed within different environments, the simulations reveal they shared a similar development. Deep convective bursts occurred in both simulations prior to genesis (Fig. 4) and were responsible for transporting high equivalent potential temperature (θ_e) air into the middle and upper troposphere while evaporative cooling led to the formation of a cold pool within the boundary layer. The development of the cold pool appears to have helped re-trigger deep convection by serving as a mechanism for ascent of high-θ_e air while the low-level wind became increasingly convergent.

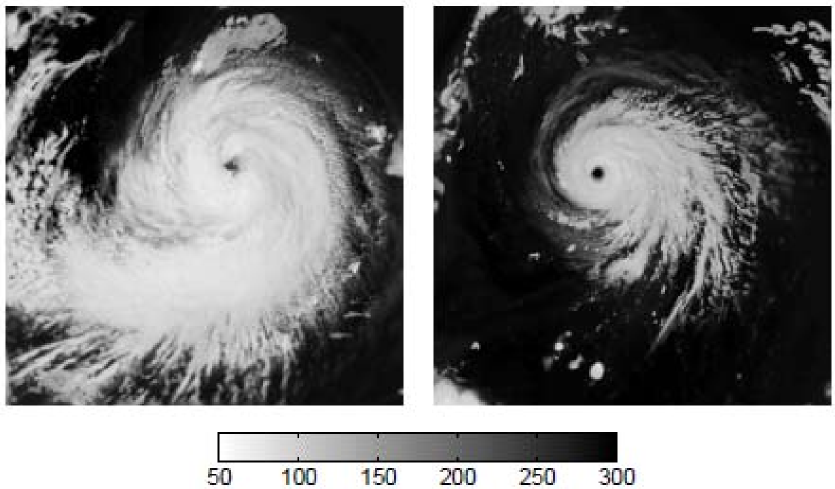

Figure 3: Model-derived outgoing long-wave radiation (W m^{-2}) image of Typhoon Ketsana 2003 (left) and Typhoon Mawar 2005 (right) after 96 hours of simulation.

Positive potential vorticity (PV) anomalies formed in the middle levels of the troposphere following the pre-genesis convective bursts and signify the presence of stratiform precipitation regions. It is hypothesized that the midlevel PV anomalies may have caused the lower-tropospheric wind profile to become increasingly convergent such that, working in cooperation with the near-surface cold pool, deep convection was able to redevelop and "spin-up" the low-level relative vorticity. It appears that the positive midlevel PV anomaly present in each simulation preconditioned the atmosphere by increasing

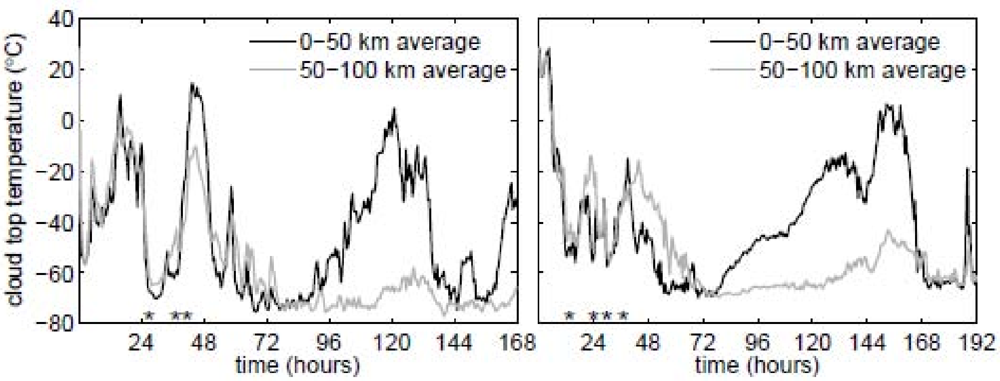

Figure 4: Azimuthally averaged (0 - 50 km radius and 50 - 100 km radius) cloud-top temperature (°C) for the Typhoon Ketsana simulation (left) and Typhoon Mawar simulation (right). Asterisks denote the time of pre-genesis convective bursts in each simulation.

midlevel inertial stability and lowering the deformation radius. This allowed for a more efficient warm core development and “spin-up” of the storms’ primary circulation once low-level convective processes became more important (e.g., Fig. 5) (Penny and Ritchie, 2009).

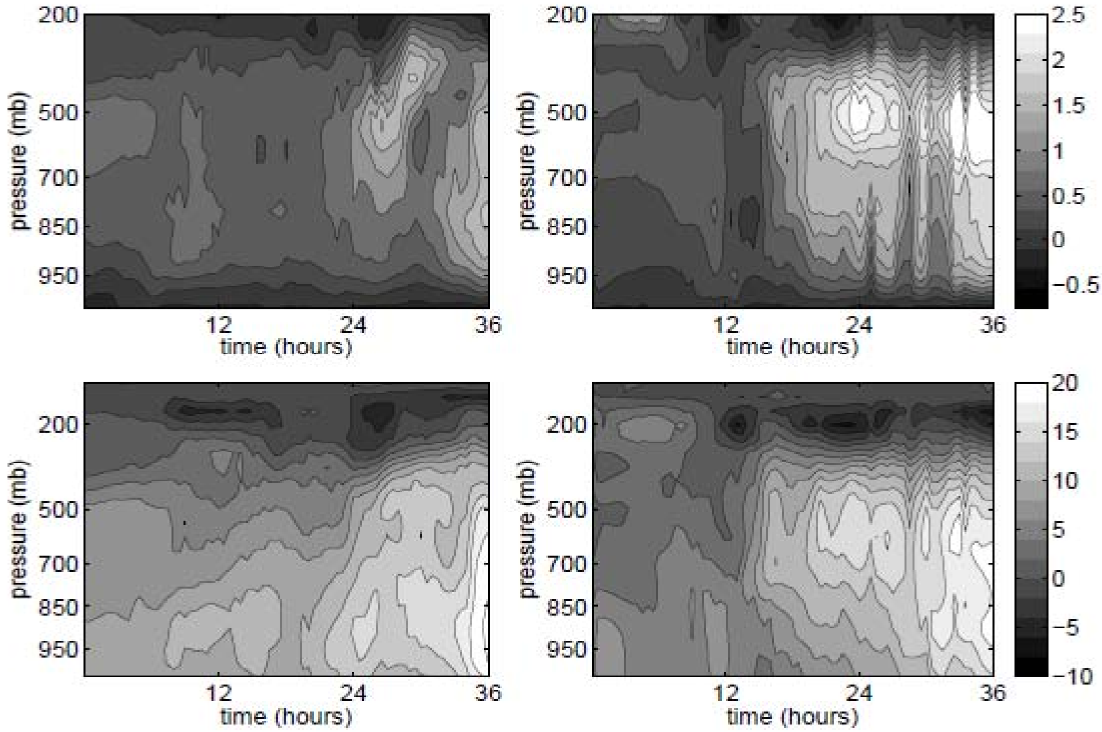

Fig. 5: Azimuthally averaged (0 - 50 km radius) potential vorticity (PVU) (top) and azimuthally averaged (0 - 100 km radius) relative vorticity ($\times 10^{-5}\ s^{-1}$) for the Typhoon Ketsana simulation (left) and Typhoon Mawar simulation (right).

IMPACT/APPLICATIONS

A combined observational and numerical simulation study of North Pacific and Atlantic tropical cyclone genesis is being conducted. An approach is planned that will allow detailed and systematic study of the detailed mesoscale properties of potential cloud clusters and the vital interactions between these and the favorable large-scale environments in which tropical cyclones finally emerge. It is important to understand these relationships to improve the forecasting of both location and timing of tropical cyclogenesis. In addition, the documentation of high-resolution structural responses in the cloud clusters during tropical cyclogenesis will allow us to gain more insight into the physical processes that lead to genesis. The greatest value-added asset would be the possibility of more accurate prediction of genesis based on a conceptual model built from the results of the satellite analysis and systematic simulations. Thus, a potential exists for direct forecast application from the increased understanding that would result from analysis of these types of complete data.

RELATED PROJECTS

Understanding the microphysical properties of developing cloud clusters during TCS-08
N00014-08-1-0410, PI: Elizabeth A. Ritchie.

This project aims to better understand the convective and larger-scale differences between developing and non-developing cloud clusters using high-fidelity observations collected during the TCS-08 field campaign along with remotely-sensed observations. These observations will help guide and constrain high-resolution simulations of real cases in the western North Pacific during the TCS-08 period.

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